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B. T. GALLOWAY, *Chief of Bureau.*

ARRANGEMENT OF PARTS IN THE COTTON PLANT.

BY

O. F. COOK AND ROWLAND M. MEADE,
Crop Acclimatization and Adaptation Investigations.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF PLANT INDUSTRY,
OFFICE OF THE CHIEF,
Washington, D. C., May 10, 1911.

SIR: I have the honor to transmit herewith a paper entitled "Arrangement of Parts in the Cotton Plant," by Messrs. O. F. Cook, bionomist, and Rowland M. Meade, scientific assistant, of this bureau, and to recommend its publication as Bulletin No. 222 of the bureau series.

Notwithstanding the great agricultural importance of the cotton plant, its peculiarities have received very little study from the botanical standpoint. This bulletin describes the general structure and habits of the plant as affected by differences in the number, position, and arrangement of the various parts.

Respectfully,

WM. A. TAYLOR,
Acting Chief of Bureau.

HON. JAMES WILSON,
Secretary of Agriculture.

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ARRANGEMENT OF PARTS IN THE COTTON PLANT.

INTRODUCTION.

The basis of all scientific study of cotton, as of other agricultural plants, is the recognition and comparison of differences. Whether experiments are being made for the breeding of better varieties or to determine the most favorable conditions or methods of culture, account must first be taken of the differences that are shown in the characters and behavior of the plants. The scientific interest and practical value of the results must depend very largely upon the ability of the experimenter to recognize such differences and to understand their relation to the development of varieties and to cultural problems.

Two principal kinds or classes of differences may be recognized in the study of such a plant as cotton. The component parts, such as the joints, leaves, flowers, or fruits, may differ, or there may be differences in the number and arrangement of parts that are otherwise alike. The body of the plant may be looked upon as a compound structure or colony built of several kinds of structural units, commonly called joints or internodes. Changes of behavior that are of serious economic importance may be brought about by changing the number and arrangement of the parts of the plants, even without altering the characteristics of the leaves, flowers, or other component units of structure.

Not only do the parts of an individual plant stand in relation to other parts of the same plant, but all the individuals of a pure strain or variety have the same system of arrangement of parts, though variously modified under different conditions of growth. The leaves and branches have definite positions on the stems, and the parts of the flowers and fruits have characteristic numbers and places, in addition to their peculiarities of form and color. Hybrids, mutations, and reversions usually show differences in arrangement of parts as well as in other characters. Differences in arrangement are often the most obvious and assist the breeder in recognizing the superior individuals and rejecting the inferior.

ARRANGEMENT OF THE LEAVES ON THE MAIN STALK OF THE COTTON PLANT.

The leaves of the cotton plant are not set at random along the stalks and branches, but are regularly arranged in ranks and spirals. In plants of normal growth it is usually easy to see that each leaf is directly above or below some other leaf and that there are three, five, or eight of these vertical ranks of widely separated leaves.

The regular spiral arrangement of the leaves is found on the main stalk and the vegetative branches. It is not apparent on the fruiting branches, for these have the joints twisted so that the leaves appear to stand in two rows.

The spiral arrangement of the leaves around a main stalk or a vegetative branch can be understood by considering the relation of any given leaf to the one next higher on the stalk. An imaginary line that would connect the insertions of the leaves would form a regular spiral, since it continues around the stalk in the same direction, to the right on some plants and to the left on others. On plants with three-ranked leaves the spiral makes one turn around the stalk in going from any given leaf to the next leaf that is directly above it. If the leaves are in five ranks the spiral makes two turns in going up to the next leaf on the same rank, while with eight-ranked leaves three turns are made. Many individual plants will be found with their stalks so bent or twisted that no regular leaf arrangement is apparent, but in the majority of cases it is easy to ascertain which of the systems is followed. The regularity of the spiral is also destroyed if the growth of the stalk has been interrupted by dry weather or other injuries that cause the formation of very short joints. In such cases the direction of the spiral may even appear to be reversed.

Instances of such irregularities have been brought to our attention in cotton raised at Palestine, Tex., in the season of 1909, by Dr. D. N. Shoemaker, of the Bureau of Plant Industry. Some of the stalks had two or three sections of shortened joints and apparent reversals of the spirals. A possible explanation may be found in the fact that boll weevils, which were unusually abundant in the early part of the season, often eat out the terminal buds of the young plants. If the growth of the stalk were continued by an axillary bud it might be expected that the direction of the spiral would often be reversed, for the vegetative branches often differ from the main stalk in the direction of the spiral.

Botanists who have made special studies of the arrangement of leaves have found it convenient to describe the different systems by fractional numbers. The numerator of the fraction shows the number of turns that the spiral makes in passing from any given leaf to the next member of the same rank, while the denominator indicates the

whole number of vertical ranks of leaves. The fraction as a whole indicates the part of the circumference of the stalk included between two successive leaves of a spiral. The most frequent arrangement of the leaves of the cotton plant is in the three-eighths spiral. This means that the leaves stand in eight ranks, that three turns around the stem are made by the spiral in passing from any particular leaf to the next that is directly above it, and that successive leaves along the spiral are separated by three-eighths of the circumference of the stalk.

NEW WORLD COTTONS WITH THREE-EIGHTHS SPIRALS.

The arrangement of leaves in three-eighths spirals appears to be a normal characteristic of all pure strains of cotton belonging to the Upland and Sea Island species (*Gossypium hirsutum* and *G. barbadense*) and to the nearly related types that are natives of tropical America. This normal arrangement appears with much regularity in varieties introduced from tropical America, when planted for the first time in the United States. With the advance of acclimatization, the leaf arrangements are varied by frequent examples of one-third and two-fifths spirals, and similar irregularities are found among native Upland varieties. Pure stocks are much more likely to have the regular three-eighths arrangement than those not carefully bred.

Variations in the arrangement of the leaves were first noticed in Egyptian-Upland hybrids, but were found later in all hybrid stocks, including many crosses between different Upland types. Hybrid plants may have a one-third, two-fifths, or even a five-thirteenths spiral arrangement, although both parents may have had the normal three-eighths arrangement, or hybrids may have the normal arrangement of the parents. The very general prevalence of the three-eighths spiral among American types of cotton warrants the suspicion that any plant without the normal three-eighths arrangement is of hybrid origin or the result of recent mutative variation.

On the other hand, there is a possibility that the regularity of the three-eighths arrangement in the newly imported stocks may represent one of the tendencies of reversion that are very frequently shown in other characters of the plants. The simpler forms of spirals may be correlated with the smaller size and more fertile habits of growth of acclimatized stocks, but if this be true some varieties should be found with the simpler spirals as a regular feature. The systems of arrangement followed by the foreign cottons in their native countries must also be ascertained before definite conclusions can be drawn regarding the effects of new conditions and acclimatization.

Mutative stocks, as far as known, differ from hybrid stocks in that all the plants of a stock have the same leaf arrangement. This may be like the stock from which the type mutated or it may be different. The only type of Upland cotton that seems to show a regular deviation

from the three-eighths system of arrangement is a peculiar variety with deeply divided leaves called "Park's Own," which is said to have originated as a mutation from the King cotton. Small plantings of this variety have shown the two-fifths arrangement with apparent regularity. Three plants raised at Kerrville, Tex., in 1908 from the seed of a Triumph mutation had a one-third arrangement. The leaf arrangement of the parent plants was not noted, but the Triumph variety has the usual three-eighths spiral.

OLD WORLD COTTONS WITH ONE-THIRD SPIRALS.

In contrast with the three-eighths system of leaf arrangement of the Central American varieties, all the newly introduced Asiatic cottons show a one-third system of leaf arrangement. Among the hundreds of plants that have been grown from imported seed, including representatives of several Old World types that are reckoned as distinct species (*Gossypium herbaceum*, *G. arboreum*, *G. indicum*, *G. neglectum*, etc.), only one exception to this rule has been noted. A single plant of a variety from Bokhara, grown at New Braunfels, Tex., in 1909, appeared to have a two-fifths arrangement of the leaves along the vegetative branches. This plant had been injured when young, so that the main axis had not developed.

Later generations of the Asiatic species from seed raised under conditions that would permit crossing with other Asiatic species have produced plants with two-fifths and three-eighths arrangements. Some of these plants with the more complex spirals were obviously hybrids, and others may have been. Although hybridization does not appear to take place between Old World cottons and New World types, crossing between different Old World cottons seems to have the same effect of inducing variations of leaf arrangement as among the Upland types of cotton, and the leaf arrangement also seems to change with the progress of acclimatization. There is a contrast, however, in the fact that in the New World hybrids or acclimatized plants the spirals tend to become more simple, while in the Old World cottons they become more complex.

ARRANGEMENT OF THE BRANCHES ON THE MAIN STALK.

At the base of each leaf of a cotton plant two buds are to be found. The true axillary bud stands just above the middle of the base of the leaf. The lateral or extra-axillary bud stands at the right or the left of the axillary bud, depending on the direction of the spiral in which the leaves are arranged.

The two buds differ in their power of forming branches. Only "limbs" are produced from axillary buds. All the branches that bear flowers and fruit before again branching come from lateral or extra-axillary buds. Near the base of the plant lateral buds may

also develop into vegetative branches instead of fruiting branches, but no normal fruiting branches have been found to grow from axillary buds.

The axillary buds usually develop into branches on only a few joints in the lower part of the main stalk. They usually remain dormant on the joints that produce fruiting branches. It often happens, however, that two buds develop at the same joint, one into a vegetative branch and the other into a fruiting branch. (Fig. 1.) In some varieties of cotton this double-branched condition of some of the lower joints of the stalk is a regular feature.

As already indicated, the differences of origin and position enable two kinds of vegetative branches to be distinguished, the true axillary limbs and the vegetative branches that rise from extra-axillary buds. Though both kinds of vegetative branches have the same appearance and function, it is desirable to recognize the difference of arrangement because the extra-axillary vegetative branches often replace the fruiting branches, to the serious detriment of the crop. Two vegetative branches, one of each kind, may appear at the same node, but this is a rather rare occurrence.

Though the limbs are always represented by buds in the axils of the leaves, the various types and varieties of cotton differ greatly in their tendencies to develop them as regular parts of the plant. In

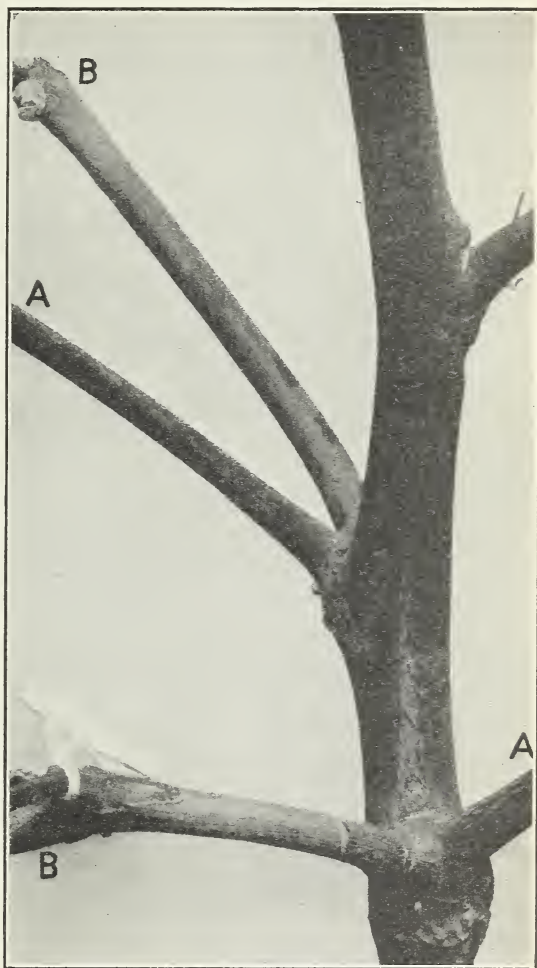


FIG. 1.—Stalk of Lone Star Upland cotton, with (A) vegetative and (B) fruiting branches from the same nodes. (Natural size.)

some varieties the axillary branches are represented only by small rudiments or mere dormant buds, or they may die and drop off, leaving only minute scars, often difficult to detect in mature plants. When the limbs are produced they usually take a more upright position than the fruiting branches and often attain a height as great or greater than that of the main axis of the plant. In plants that have been injured or pruned or that have had their growth interrupted by dry weather, limbs may develop late in the season, either from basal joints of the stem or from joints that have already produced fruiting branches. At the base of the plant the vegetative branches usually grow more rapidly than the limbs, so that the latter may be forced to one side or their development arrested, but near the middle of the plant a limb and a fruiting branch may occur at the same node and may develop to about the same extent. In the Upland types of cotton the vegetative branches seldom occur above the fifth node from the base of the plant. The Egyptian cotton has a much stronger tendency to produce vegetative branches.¹

Vegetative branches often grow as tall or taller than the main stalk and are generally larger than the limbs when both are produced on the same plant. They usually develop only at the base of the plant, but are often quite numerous and may even replace the fruiting branches over the whole plant, as often occurs in the first generation of foreign cottons introduced into the United States. Plants that develop only vegetative branches are rendered completely sterile. Having no fruiting branches they are unable to form any flower buds. This condition of sterility is to be distinguished from another that is still more common in unacclimatized stocks. Although fruiting branches are present the flower buds may all be abortive in the early stages, so that no flowers are produced. Moreover, plants that are able to produce an abundance of flowers may still fail to set any bolls.

Hybrids may also be rendered sterile in the same ways. An important step in the improvement of all cottons by selection is the removal of all plants showing a tendency to multiply vegetative branches at the expense of fruiting branches. Even though large branching plants may produce large quantities of cotton, seed from such plants should not be selected; furthermore, the crop ripens late and the yield per acre is generally less than can be secured from small plants. The presence of the boll weevil greatly increases the disadvantage of growing late varieties.

A special study of the branching habit of Egyptian cotton in Arizona has been made by Mr. Argyle McLachlan, of the Bureau of Plant

¹See "A Study of Diversity in Egyptian Cotton," Bulletin 156, Bureau of Plant Industry. Also "Dimorphic Branches in Tropical Crop Plants: Cotton, Coffee, Cacao, the Central American Rubber Tree, and the Banana," Bulletin 198, Bureau of Plant Industry.

Industry, who finds that the vegetative branches are produced for 12 to 14 nodes from the base of the main stalk in plantings of newly imported seed, whereas in acclimatized strains the number of vegetative branches is distinctly reduced and the production of fruiting branches usually begins five or six joints closer to the ground.

Weather that is dry enough to retard the growth of the plants also discourages the formation of limbs and vegetative branches, while humid conditions favor the production of both. After a prolonged drought at San Antonio, Tex., during the season of 1909, no plants of either New World or Old World cottons could be found with limbs, except as short rudiments, though many of the basal extra-axillary vegetative branches were well developed. The dry weather was apparently able to suppress the limbs without seriously restricting the growth of the extra-axillary vegetative branches that had begun to develop early in the season.

With an abundant supply of water the limbs may be forced into vigorous growth and may gain a predominance over the vegetative branches, as was well illustrated at Del Rio, Tex., during the same season. There the cotton from the same stocks as those in the San Antonio experiment received a plentiful supply of water, and limbs were much more numerous than vegetative branches. The vegetative branches usually outnumber the limbs unless the latter have been forced into growth late in the season.

ARRANGEMENT OF THE LEAVES ON THE LIMBS AND VEGETATIVE BRANCHES.

The arrangement of the leaves and buds on both the axillary limbs and the vegetative branches is the same as on the main stalk of the cotton plant. If the main stalk has the normal three-eighths arrangement all the limbs and vegetative branches follow the same system, no matter how many branches the plant may have. Deviations from the normal spiral on the main stalk are also accompanied by abnormal arrangements on the vegetative branches.

There seems to be little or no regularity in the directions of the leaf spirals on either the vegetative branches or the limbs. Often several succeeding vegetative branches will turn their spirals in the same (right or left) direction, while again they seem to alternate their direction with some regularity. The direction of the spirals of the vegetative branches often appears to agree with that of the main stalk in cases where the vegetative branches are few in number, but if the branches are numerous, differences in the direction of the spirals can usually be found. If a limb and a vegetative branch develop at the same node, their spirals may follow the same direction or may be opposed.

ARRANGEMENT OF THE FRUITING BRANCHES.

The fruiting branches of the cotton plant are developed from the extra-axillary buds that stand slightly above and at one side of the axillary buds of the main stalk and the vegetative branches. Fruiting branches are very seldom produced from the lowest nodes of the main stalk or the vegetative branches. Even when no limbs or vegetative branches are developed at the base of the plant, the fruiting branches usually do not appear below the fourth or fifth joint of the stalk. When vegetative branches are present there is often an interval between them and the fruiting branches, a condition found by Mr. McLachlan to be especially prominent in the Egyptian cotton in Arizona.



FIG. 2.—Two internodes of a fruiting branch of Upland cotton. (Natural size.)

The node at which the fruiting branches are first produced on the plant varies considerably, not only in the different varieties and types, but also in different conditions of growth. In Egyptian cottons this zone is from the eighth to the fourteenth nodes, while in the Upland cottons it is from the fourth to the fifth. In Upland cotton fruiting branches may begin to be formed very low down, only one or two nodes above the cotyledons, while in Egyptian cottons they generally begin much higher up, between the tenth and the fourteenth nodes. When the vegetative growth is very luxuriant the fruiting branches may be still higher up, or they may fail altogether, all being replaced by branches of the vegetative sort, as already noted.

Fruiting branches have a nearly horizontal instead of a vertical or ascending position. The basal joints are also longer than those of the vegetative branches, and the other joints are usually shorter, twisted, and more or less zigzag. (Fig. 2.)

ARRANGEMENT OF THE LEAVES AND FLOWERS ON THE FRUITING BRANCHES.

As previously stated, the leaves of the fruiting branches do not show the definite leaf arrangement of those on the main stalk and vegetative branches. The twisting of the joints of the fruiting

branches brings the flower buds into an upright position and allows the leaves to stand out in two alternate rows along the sides of these branches. If one joint of the fruiting branch is twisted to the right, the next is twisted to the left, and so on in regular alternation, bringing every second leaf nearly in line with the one two nodes distant.

The direction of the twist of the basal joint also appears to have a regular relation to the position of the branch on the main stalk. Branches that come out at the right of the leaf axil usually have the basal joint twisted to the right; others to the left. The twisting brings the first leaf of the fruiting branch opposite the leaf on the main stalk, at the base of the branch. This alternation suggests the possibility that the fruiting branch may represent a specialized branch from the base of the axillary limbs.

The leaves of the fruiting branches, unlike those of the main stalk and vegetative branches, are often irregular in outline. If there is an odd number of lobes those on the side of the blade away from the branch are usually much larger than those alongside of the branch. These leaves often have two nectaries, or only one, instead of the three nectaries common to the leaves of the main stalk, one borne on the midvein and the second on the primary vein subtending the large lobe on the side of the blade away from the branch.

The flower buds do not come out from the axils of the leaves, but often appear to be separated by almost half the diameter of the stem. In cluster cottons, or others that have abnormal branches, the pedicel, or stem of the flower, appears as a continuation of the joint of the fruiting branch and lacks the usual absciss-layer that allows the blasted buds to fall off or the bolls to separate at maturity. This may indicate that the fruiting branches have what botanists describe as the sympodial method of growth, as though each joint were terminated by the flower and the next joint formed by the development of a new lateral bud.

In addition to the bud that continues the growth, there are buds in the axils of the leaves of the fruiting branches, and if these develop they may produce vegetative branches of the usual form. In other cases the axillary buds of the fruiting branch may produce very short vegetative branches, and these may give rise in turn to very short fruiting branches, so that one joint of a fruiting branch may appear to bear two or three bolls in an exceptionally fertile plant. Careful examination will show that only one boll is borne directly on the joint and that the others come from branches of the short axillary.

In the Asiatic species the flowers are often pendent and are borne somewhat on the sides of the branch, more nearly opposite the leaves. The leaves are arranged the same as those of the Upland and nearly related types of cotton.

ARRANGEMENT OF THE INVOLUCRAL BRACTS AND BRACTLETS.

Each flower bud of the cotton plant is protected by an involucre composed of three specially reduced and modified leaf-like organs, technically called bracts. Inside the involucre, between the bracts and the bud proper, still smaller leaf-like organs, the so-called bractlets, may occur. Both the bracts and the bractlets give indications of regular arrangement.

Two of the bracts are of equal size and are often appreciably larger than the third. The small bract is always borne on the side of the flower that faces outward, toward the end of the branch. (Fig. 3.) Bractlets are most likely to be associated with this small bract. If only two bractlets are present, as frequently happens, they stand at

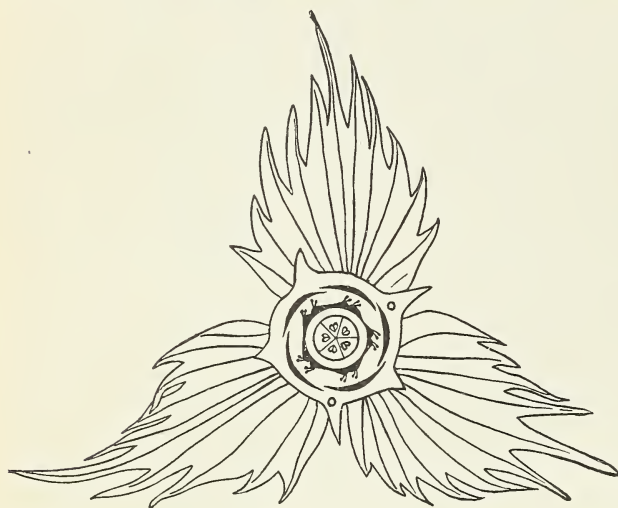


FIG. 3.—Diagram showing the relation of parts in the cotton flower. (Bracts and calyx teeth natural size.)

either side of this small outer bract. In the Kekchi cotton and other Central American types the bractlets often occur in pairs, alternating with the bracts, though it is rather unusual to find a complete set of six bractlets.

When a fourth involucreal bract occurs, it develops at one side of

the smaller bract, the side that is toward the leaf of the same node. This additional fourth bract has always been found to be smaller than the third and is even more likely to be accompanied by bractlets.

The laciniae, or teeth, of the younger bracts are often bent or twisted in one direction and overlap those of another bract, completely inclosing the young bud. (Fig. 4.) At one node the laciniae twist in one direction and at the next the direction is reversed. This twisting is opposite in direction to that of the internode which bears the flower and in the same direction in which the petals of the same flower overlap.

ARRANGEMENT OF THE LOBES OF THE CALYX.

The calyx of the cotton flower is usually very small, the usual function of the calyx, to protect the young bud, having been assumed by the much larger involucreal bracts. The calyx forms in most kinds of

cotton merely a shallow cup around the bases of the petals. The margin of the cup is more or less divided or produced into five lobes, sometimes short and broad, sometimes long and pointed. The assumption that these lobes represent as many sepals or bracts of some ancestral relative is warranted by their position and by the fact that a transparent line is also sometimes to be seen, extending from the sinus between two lobes to the base of the calyx.

Seldom, if ever, is a calyx found with lobes of uniform size. Usually there are two large lobes, two small lobes, and one of intermediate size. In the Egyptian cotton and in some of the Asiatic species, calyxes are found with the margin almost evenly truncate, but it is usually possible to distinguish the five lobes and to see that they are of unequal size.

One of the small lobes stands between the two large lobes and is always on the outer face of the calyx, that is, opposite to the small outer bract of the involucre. (Fig. 5.) The other small lobe is between one of the large lobes and the intermediate lobe, but it may be on either side of the intermediate lobe. The position of the second of the small lobes with reference to the intermediate lobe has a constant relation to the twisting of the other parts of the flower. If the petals twist to the right the intermediate lobe is at the right of the small lobe, and vice versa. These relations can usually be ascertained without much difficulty, though abnormal calyxes are occasionally found, especially in connection with irregularities in the petals and other floral organs.

In view of the fact that organs of intermediate form are often found, it is not unreasonable to consider the so-called calyx as belonging to the same series of modified leaf organs as the outer involucral bracts. In other words, the so-called calyx may be looked upon as the inner involucre rather than as a true calyx. This view seems to give a better understanding of the arrangement of parts. It would explain, for example, the further fact that the smallest lobe, on the outer (distal) side of the calyx, seems to stand directly opposite to the small outer bract of the involucre, whereas none of the other lobes appears opposite to the bracts. The small outer involucral bract would commence and the smallest lobe of the calyx would complete one whorl or series of eight leaves in the usual system of leaf arrangement.



FIG. 4.—Bracts of Upland cotton inclosing bud, showing twisted teeth. (Natural size.)

The two large lobes of the calyx alternate with two of the involucreal bracts, and each of these lobes is usually provided with a nectary. The intermediate lobe and the remaining small lobe do not appear to be definitely alternate or opposite to any of the bracts. (Fig. 6.) Often the intermediate lobe approaches the size of the large lobes, especially in the Upland varieties. It then appears more nearly alternate with the involucreal bracts and usually has a nectary at its

base, like the other large lobes. In other cases the nectary is usually absent.

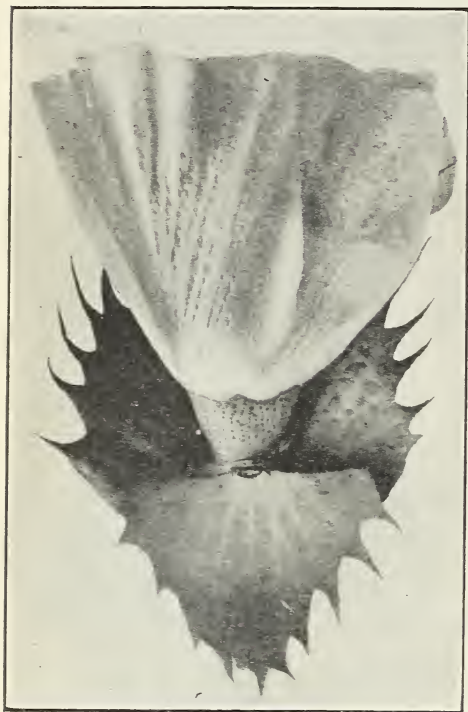


FIG. 5.—Flower of Upland cotton, from the side, showing the position of the small calyx lobe opposite the smallest bract. (Natural size.)

ARRANGEMENT OF THE INTRACALICARY ORGANS.

Inside of the calyx of the cotton flower, between the calyx and the petals, a series of small, greenish, oboval or spatulate organs may often be found. (Fig. 7.) The complete number of these organs is five and they are arranged in regular alternation with the lobes of the calyx. The size is extremely variable, so that the full number is seldom to be seen by the naked eye. Some of them are usually represented by minute rudiments visible under a lens as small tufts of hairs at the base of the calyx. When very

large they may extend to the

margin of the calyx, and in rare cases may project slightly above it.

That these organs are arranged in alternation with the lobes of the calyx is rendered the more apparent by the fact that they stand in front of faint transparent lines that mark the sutures between the component parts of the calyx. This was first observed in the Willet's Red Leaf variety of Upland cotton, where the deep-red color of the outside of the calyx makes the transparent lines more distinct. These lines are often very faint, but they seem to be generally present.

The intracallicary organs may be free from the calyx to near the base or they may be united with the calyx at the back, along the sutures

which separate the calyx lobes. They are somewhat thickened and fleshy at the base, but become very thin toward the apex. Like other parts of the calyx they are well spotted with oil glands and have faint veinlets radiating from a transparent median line.

The fact that these organs are frequently adherent to the calyx lobes and that they often have a transparent median line, somewhat like the sutures that separate the lobes, suggests that they may represent ingrown margins of the calyx lobes. Or they may be considered as stipular elements of the calyx lobes, brought into expression in an irregular manner, like the bractlets that appear on the outside of the calyx. If viewed as independent organs, apart from the calyx, it is necessary to suppose that they represent rudimentary internodes or joints of the floral branch, intercalated between the calyx and the corolla, perhaps analogous to the suppressed or rudimentary branches that occur from the interval between the vegetative branches and the fruiting branches.

If reckoned as parts of the calyx, the intracalicular organs add to the morphological



FIG. 6.—Flower of Upland cotton, from below, with bracts removed, showing the arrangement of calyx lobes, petals, and nectaries. (Natural size.)

analogies between the calyx and the involucre. If supposed to represent independent metamers, the intermediate position of the intracalicular organs would indicate that the so-called calyx is really a part of the involucre, since it is separated from the corolla by the intracalicular organs, which might even be considered as rudiments of the true calyx. It is possible that a study of the irregularities in the formation of the involucre in relation to different systems of phyllotaxy would give more definite indications regarding some of the morphological questions. The three bracts and the five calyx lobes would represent one complete whorl in a three-eighths system, but not in a two-fifths or a one-third system.

ARRANGEMENT OF THE PETALS.

The five petals of the cotton flower stand in alternation with the five lobes of the calyx and are inserted on the base of the staminal column, one petal at the base of each of the five lobes or ridges of the column. Abnormal flowers sometimes occur with six or more petals or with small petal-like organs on the base of the staminal column, above the large petals—another indication of the relation of the petals to the staminal column.

The arrangement of the five petals of the cotton flower in the bud

may be described as convolute; that is, each petal overlaps the next. Sometimes the petals overlap to the right, sometimes to the left. If the internode that bears the flower twists to the right, the petals of the flower overlap to the left, and vice versa.

Looking into the flower, it appears that the petals and the stamens twist in the same direction. The direction of the twisting of the petals is reversed in each succeeding flower, as is the case with the internode of the fruiting branch which bears the flower. Finally, the petals twist in the same direction as the teeth of the bracts and stamens of the same flower. (Fig. 8.)

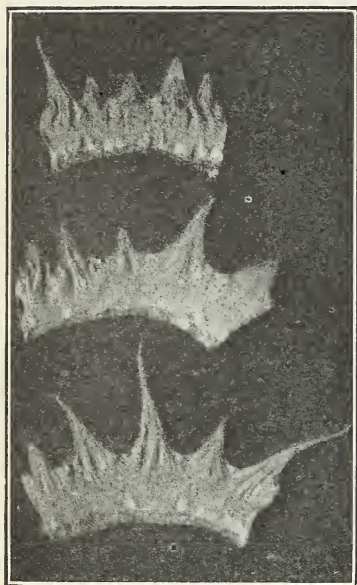


FIG. 7.—Calyxes of Cochin China Upland cotton, showing intracallicary organs alternate with calyx lobes. (Slightly enlarged.)

ARRANGEMENT OF THE STAMENS.

The cotton flower has a large cluster of stamens, often as many as 90, all inserted on a tubular sheath of tissue known as the staminal column. This surrounds and covers the pistil, allowing only the stigmas and part of the style to project beyond the cluster of stamens. If the style is long, as in the Egyptian cotton, the stigma may be carried well above the stamens, so that insects may be required for fertilization. In the Upland cottons the style is generally shorter and the stigmas may remain buried among the stamens, insuring self-fertilization.

Though the stamens may at first appear to have no regularity of arrangement, it is usually possible to see that they spring from five vertical ridges of the staminal column, often ending in as many teeth

or lobes. The position of these ridges is opposite to that of the petals. Often there appear to be two rows of stamens on each ridge, one on either side. All of the filaments are usually bent in the direction of the twist of the petals and stigmas of the same flower.

The staminal column is reckoned by botanists as one of the peculiar characteristics of the mallow family, to which the cotton belongs. Some of the relatives of the cotton have only 5 or 10 stamens and little or no development of the staminal column. Abnormal cotton flowers are sometimes found with the column very short or split to the base into five separate lobes that may represent as many original stamens. On some plants all gradations may be found between this form of separate short lobes bearing few stamens, sometimes only two, and the elongated column of ridges bearing an indefinite number of stamens.

In other words, the staminal column may be looked upon as composed of the united filaments or bases of the many stamens that are separated only at the end. The presence of partly divided anthers and of



FIG. 8.—Flower of Upland cotton, from above, showing the position of petals, stigmas, and stamens. (Natural size.)

branched filaments, bearing two, three, or four anthers, also suggests the possibility that the large number of stamens now present in a normal cotton flower may have been attained by the subdivision or branching of an originally small ring of stamens. This would explain why the staminal tube has been developed as a common base for all the stamens instead of having them separately inserted, as in most of the families of plants that have numerous stamens.

ARRANGEMENT OF THE CARPELS.

The number of stigmas of the cotton flower is the same as that of the carpels, or "locks," of the ripe seed pod or "boll." In contrast

with the generally constant number of bracts, calyx lobes, and petals, the number of carpels is always varied, even among the flowers of the same plant. No variety of cotton is known to have a constant number of carpels. In Upland cotton four-locked and five-locked bolls are the rule; in Egyptian and Sea Island varieties the bolls are three locked and four locked. Three-locked bolls are occasionally found in Upland cotton, and two-locked bolls in Egyptian. Six-locked bolls are of rare occurrence. Abnormal bolls with still larger numbers of locks result from fasciation, especially in the "cluster" varieties of Upland cotton.

When the number of carpels is less than five it does not appear that they have any regularity of arrangement with reference to other parts of the flower, but when five carpels are present they appear to stand in alternation with the lobes of the staminal column and the petals and opposite the calyx lobes. The stigmas are not usually twisted, but sometimes they are bent in the direction taken by the stamens and petals.

ARRANGEMENT OF THE HAIRS ON THE SURFACE OF THE SEED COAT.

Although not to be considered in detail in the present paper, the distribution of the hairs on the surface of the cotton seed is another subject worthy of study from the standpoint of position and arrangement. In most of the different species and varieties of cotton the seed produces two distinct kinds of hairs. The long hairs represent the commercial fiber, or lint, and the shorter, finer hairs represent the fuzz left on the seed after ginning. The fuzz may be white like the lint, but is often green or brown. If no fuzz is produced the seeds are left black and naked after ginning. Naked-seeded variations are quite common in some varieties of Upland cotton and are very undesirable because the absence of fuzz is nearly always accompanied by a serious reduction in the amount of lint. In a few cases plants have been found with neither fuzz nor lint. Though the presence of fuzz seems to be correlated with abundance of lint, very fuzzy seeds sometimes have very few of the long lint fibers; sometimes none at all.

In the Upland type of cotton the two kinds of hairs are mixed together over the whole surface of the seed, but in other sorts there are definite differences in the position of the lint and fuzz. In the Egyptian cottons there is a strong tendency to restrict the fuzz to the ends of the seed and the lint to the intermediate position. A peculiar form of Sea Island cotton found in a locality called San

Lucas, in eastern Guatemala, between Cajabon and Senahu, shows the most extreme specialization of the two kinds of hairs on the seed. The lower half of the seed is without lint, but has a dense, velvety covering of bright-green fuzz. The upper half of the seed produces lint but no fuzz.

In addition to the positional relation of the fuzz and lint there are also differences in the lengths of the lint fibers on different parts of the seed. Some varieties of Upland cotton have a strong tendency to have the fibers of the upper part of the seed distinctly longer than those of the lower part, so that when the lint is parted and combed out from the seed a "butterfly" outline is formed. The butterfly tendency is undesirable because inequality in the lengths of the fibers lessens the commercial value of the cotton for spinning purposes. Even when the long fibers are not all restricted to the upper part of the seed, the lower part may show an evident preponderance of shorter fibers.

ARRANGEMENT OF THE ROOTS AND UNDERGROUND SHOOTS.

The central stalk of the cotton plant extends into the ground to form the taproot. The lateral roots arise in four rows from four shallow vertical grooves, one on each side of the taproot. The regularity of arrangement is often obscured by the bending and twisting of the taproot, as well as by the fact that the lateral roots take different directions and develop very unequally. But most plants show definite indications of an arrangement of the roots in rows, and in occasional individuals, where all the roots happen to project at right angles, the four-ranked character of the root system is very plain, even in old plants. (Fig. 9.)

In addition to the various kinds of buds and branches already described, the cotton plant is able to produce underground shoots from the same grooves as the roots. The underground shoots have at first a rounded or irregular form, like root nodules or galls, and may represent modified root primordia. The nodules grow to various sizes, sometimes attaining a diameter of nearly an inch before showing the leafy bud that develops into a vegetative branch. The similarity to crown galls may prove interesting and even worthy of study from the standpoint of pathological tissues.

Subterranean shoots seem to be developed much more freely in the Egyptian cotton than in Upland varieties. They seemed to be generally distributed over a whole field of several acres of Egyptian cotton at Bard, Cal., where nearly all of the plants were killed down to the ground in the winter of 1910-11. The roots of all the plants

that were dug up in different parts of the field were found to be alive and showed in May, 1911, many different stages of development of the subterranean shoots. Several of the lower leaves of such branches were small and distorted, but normal leaves were produced on shoots that had emerged from the ground.

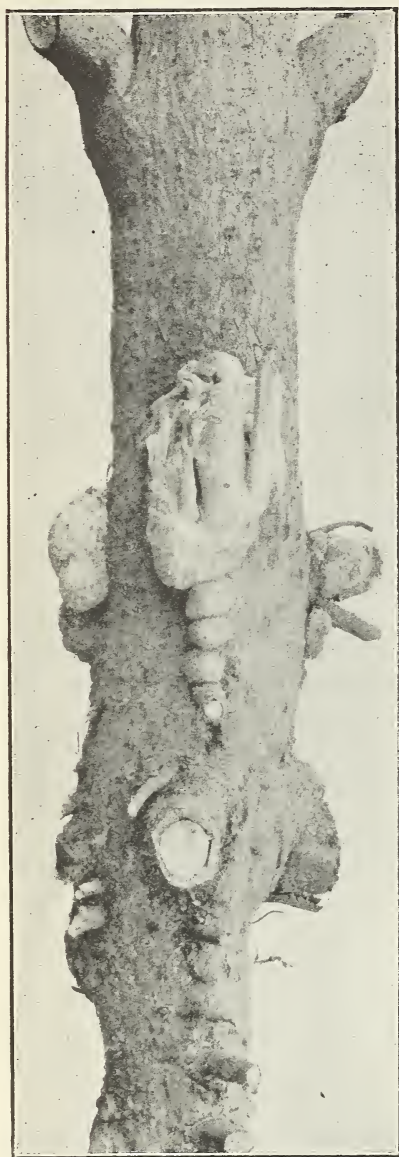


FIG. 9.—Taproot of Egyptian cotton, showing the arrangement of lateral roots and underground shoots.

In cases where the plants had not been killed too far down, new shoots had been formed at the axils of the cotyledons and no subterranean shoots or nodules were found. If the buds in the axils of the cotyledons had developed into limbs in the previous year, new adventitious buds were produced from the swollen bases of the limbs. The branches from such buds were very small and slender at first, quite unlike the large, fleshy excrescences that gave rise to the underground shoots. The lower part of the stalk, representing the hypocotyl of the seedling, between the cotyledons and the surface of the ground, seems to have no power of producing adventitious buds. Nor did any of the nodules appear upon the lateral roots of any of the plants that were dug up. They seem to be entirely confined to the same lines or grooves which give rise to the normal lateral roots, and often show very clearly the same arrangement in four vertical rows. (Fig. 9.)

CONCLUSIONS.

Plants are compound organisms built up by many units of structure, the internodes or metamers. In studying the anatomy of a plant like cotton, two principal classes of differences may be taken

into account: (1) Differences in the characteristics of the component parts of the plant and (2) differences in the number or the arrangement of the component parts.

The leaves and branches of the cotton plant have a regular arrangement in spirals. The normal arrangement in the Upland, Sea Island, and Egyptian varieties of cotton and nearly related types is in three-eighths spirals. Old World cottons, on the other hand, have the leaves and branches in a one-third spiral.

Hybridization produces deviations from the normal number of spirals of the parent stocks. Among the Old World types of cotton, hybrids show a tendency to produce plants with the more complicated arrangement of leaves, while among the Upland hybrids the tendency is to arrangements simpler than normal. Mutative variations may agree in leaf arrangement with the parent stock or may show different arrangements.

The cotton plant has two kinds of branches, differing in arrangement as well as in other characters. Fruiting branches develop laterally from extra-axillary buds at the side of the axillary buds, which produce the limbs. Extra-axillary buds may develop into vegetative branches and replace fruiting branches, but no normal fruiting branches are produced by axillary buds.

The leaves of the limbs and vegetative branches of the cotton plant have the same spiral arrangement as those of the main stem, though the direction of the spiral on the limbs and vegetative branches may be opposed to that on the main stalk. Each internode of the fruiting branch is twisted in the opposite direction from the one preceding, bringing the leaves in two alternating series along the sides of the branch and the flowers into an upright position.

The involucre of the cotton flower is composed of three bracts, two of equal size and one smaller. The small bract is always on the outer or distal side of the flower, toward the end of the branch. Two bractlets frequently appear on either side of the small bract in United States Upland varieties, while in certain Central American types a complete series of six is sometimes developed, one on either side of the three bracts. The teeth of the bracts when twisted follow the same direction as the overlapping of the petals.

The calyx of the cotton flower has five lobes distinctly unequal in size, two large, two small, and one intermediate. One of the small lobes stands opposite the small bract of the involucre, between two large lobes. The arrangement of the other lobes varies in relation to that of other parts of the flower.

Small flaplike organs are often inserted between the calyx and the petals, arranged in alternation with the calyx lobes. These intracalicular organs may be considered as supernumerary calyx lobes or as

representing free stipular elements of the calyx lobes. In either case they support the view that the calyx lobes are homologous with the bracts of the outer involucre. In other words, the calyx of the cotton plant may be looked upon as an inner involucre.

The petals of the cotton flower are opposite the lobes of the staminal column and overlap in the same direction as the stamens are bent. This direction conforms to the twisting of the internode of the branch bearing the flower and is reversed in the flowers at each succeeding node.

The stamens are arranged on the staminal column in five vertical rows, about the pistil, opposite the petals, and turn in the same direction as the overlapping of the petals. The paired positions and frequent branching of the stamens suggest the development of the compound staminal column by the subdivision of a few primitive stamens.

There is a persistent irregularity in the number of carpels, in the flowers and fruits of the same plant. The range of normal variation is from two to four carpels in the Egyptian cotton and from three to five carpels in the Upland cotton. When the number is five, the stigmas and carpels alternate with the petals and the lobes of the staminal column.





